

Research Article

Pre-service primary teachers' STEM design experiences

Sule Elmali¹ and Fatime Balkan Kiyici²

¹Sakarya University, Faculty of Education, Türkiye (ORCID: 0000-0002-5203-6246)

²Sakarya University, Faculty of Education, Türkiye (ORCID: 0000-0002-4407-8307)

The aim of the research was to examine pre-service primary teachers' experiences while creating a STEM design. The effect of the STEM design process on the STEM self-efficacy levels of pre-service teachers and the associating levels of the created designs with STEM dimensions were also examined. 52 pre-service teachers were the participants of this study. Data were obtained from the teacher STEM self-efficacy scale, open-ended forms, and designs associated with the STEM fields rubric. It was determined that the STEM design experience significantly increased the pre-service teachers' self-efficacy. The pre-service primary teachers had difficulties identifying the problem, choosing tools, calculating costs during the design process, and discussing their lack of knowledge and experience. They associated their designs well with science and mathematics but not with technology and engineering. During the design process, they faced challenges in identifying the problem, selecting appropriate tools, and estimating costs, which they attributed to their lack of knowledge and experience. Thus, examining the competencies of pre-service teachers teaching STEM approach is suggested, especially by supporting technology and engineering dimensions more and guiding them with sample practices.

Keywords: Pre-service primary teachers; STEM education; STEM self-efficacy; Teacher education

Article History: Submitted 21 May 2024; Revised 15 November 2024; Published online 24 April 2025

1. Introduction

Complex skills such as problem-solving, creativity, and critical thinking are among the features expected from 21st-century individuals. It is essential to have multidimensional elements that include life skills such as communication, cooperation, entrepreneurship, and flexibility, the requirements of the century we hold (Partnership for 21st-Century Learning [P21], 2019). Science, Technology, Engineering and Mathematics [STEM] education, an interdisciplinary teaching approach, provides significant potential for developing these competencies in students (Bybee, 2010; Miller, 2019).

STEM education includes students' awareness of daily life problems, problem-solving, research, and finding the best solution (Meng et al., 2013; Sutaphan & Yuenyong, 2019). A society based on a STEM workforce is an essential indicator for producing innovative products and services and economic development (Meng et al., 2013). STEM education is crucial in countries such as Japan, South Korea, Singapore, and China, which have shown significant economic developments in recent years (Blackley & Howell, 2015). Considering that STEM education is practiced from an

Address of Corresponding Author

Sule Elmali, PhD, Sakarya University, Faculty of Education, 54300, Sakarya, Türkiye.

✉ suleelmali@sakarya.edu.tr

How to cite: Elmali, S., & Balkan Kiyici, F. (2025). Pre-service primary teachers' STEM design experiences. *Journal of Pedagogical Research*, 9(3), 25-42. <https://doi.org/10.33902/JPR.202528478>

early age in many countries worldwide, the value of education at this level comes to the fore to encourage students to STEM-oriented areas.

Even though there is an interest in STEM practices in primary school children, this interest decreases over time (Greca Dufranc et al., 2020; Murphy & Beggs, 2003). Additionally, international indicators such as Trends in International Mathematics and Science Study [TIMSS] and Program for International Student Assessment [PISA] show that the number of students interested in science and technology has decreased (Pimthong & Williams, 2021). At this point, primary school teachers have a significant role to reverse this situation. In the case of the familiarity of primary school teachers with STEM design practices, it would provide opportunities to conduct an integrated education approach to start from the primary school level. Thus, teachers need to conduct STEM activities that will attract students' attention and direct students to STEM-oriented career choices from an early age (Siew et al., 2015). Sufficient content knowledge and experience are needed to encourage and deepen students' interest in STEM content and applications (National Research Council [NRC], 2011). Despite the purpose of STEM education being emphasized as the country's economic growth and the need for a qualified workforce (Charette, 2014; Lee et al., 2019), during the teacher training process, both in-service and pre-service teachers generally neither have enough STEM knowledge nor have enough opportunities to design lessons and practice (Blackmore et al., 2018; Nadelson et al., 2009; Pimthong & Williams, 2021). Several studies have explored affective factors among pre-service and in-service teachers, including attitudes toward STEM (Zhou et al., 2019), opinions (Geng et al., 2019), perceptions (Kurup et al., 2019), and awareness (Bakırcı & Karışan, 2018). However, to gain a more comprehensive understanding of these affective dimensions, further empirical research is needed (Le & Bui, 2021; Xie et al., 2015).

Regarding STEM practices, most in-service primary teachers report challenging STEM programs, stating they are not sufficiently exposed to qualified STEM education (DiFrancesca et al., 2014; Hourigan et al., 2022). Furthermore, they lack confidence due to limited disciplinary STEM content and pedagogical knowledge and have trouble with time and scheduling (Lesseig et al., 2016). In addition, Plumley (2019) revealed that fewer than half of primary science teachers had at least one college course in chemistry, environmental science, or physics. Nevertheless, almost none had coursework in engineering, and less than three percent felt prepared to teach science in primary grades.

Since it is essential for primary school teachers' understanding of STEM and ability to apply STEM activities successfully, which depends on gaining qualified educational experience and being supported, it comes to how this support is given during pre-service education. Pre-service primary teachers should gain enough professional development to understand the nature of STEM integration and implement it successfully (Pimthong & Williams, 2018). Pre-service primary teachers stated that the science-related content they took was insufficient, and they were unprepared to teach STEM when they graduated (Prinsley & Johnston, 2015). Thus, it is vital for them to gain experience by designing suitable learning environments for pre-service primary teachers to perform STEM practices successfully before graduation. One factor affecting teachers' behavior in the educational environment and their ability to organize the teaching environment is their level of self-efficacy. Self-efficacy is "beliefs in one's capabilities to organize and execute the courses of action required producing given attainments" (Bandura, 1997, p.3).

Self-efficacy has four sources such as mastery of experience, vicarious experience, verbal persuasion and physiological and emotional states (Bandura, 1997; Zakariya, 2020). It is also emphasised that mastery experience is the most substantial factor because it provides authentic evidence by evaluating the results of past experiences (Bandura, 1997; Pajares & Schunk & 2001). Self-efficacy affects the teachers' confidence and is related to instructing their lessons effectively (Depaepe & König, 2018). Since self-efficacy is an essential predictor of the motivation required for a task or task, individuals with high STEM self-efficacy perform better in STEM disciplines and persist longer than those with low STEM self-efficacy (Rittmayer & Beier, 2009). Thus, teachers

should have the confident and competent to perform STEM implementations (Gurler, 2022; Stohlmann et al., 2012; Yaman et al., 2018).

It is crucial to develop pre-service teachers' self-efficacy through STEM practices and reveal the effect of the implementation process and determine what they experience (Nadelson et al., 2013). Furthermore, a detailed examination of the pre-service teachers' qualities of integrating STEM fields will determine what kind of knowledge and integration inadequacy in these dimensions and give an idea about the strategies to be followed, focusing specifically on the challenges they experience (Salar, 2021). As they become primary school teachers, it is essential for them to figure out how to develop STEM activities and to be able to teach effectively. Knowing the features suitable for the structure of STEM fields will contribute to the interdisciplinary integration of the STEM process. They need to have a strong understanding of STEM fields and carry out an interdisciplinary process by integrating these fields (Pimthong & Williams, 2018). Less is known about the technology and engineering dimensions of STEM which might be effective on STEM confidence (Madden et al., 2016).

In this study, we thought that STEM practices would be effective with pre-service primary school teachers in terms of having STEM understanding and pedagogical content. Furthermore, it would be beneficial for them to reach a certain content knowledge in STEM fields and to facilitate their understanding of the interdisciplinary processes and relations of STEM (Salar, 2021). Determining the self-efficacy of pre-service primary teachers in STEM and identifying their deficiencies in the situations would contribute to the cases to be focused on for primary school teachers to teach STEM (Nadelson, 2013). Therefore, we aimed to examine the experiences of the pre-service primary teachers within the scope of the 'Science Teaching' course by having them perform a STEM design practice and evaluate the level of relating their designs with STEM dimensions. The effect of the STEM activity development process on the self-efficacy levels of STEM teaching was also investigated. In this context, the following questions were addressed:

RQ 1) How does participation in STEM design practices influence pre-service primary teachers' self-efficacy perceptions?

RQ 2) How do the pre-service primary teachers decide on their designs during the STEM design practice process?

RQ 3) What difficulties do pre-service primary teachers face during the STEM design process?

RQ 4) At what level do pre-service primary teachers relate their designs with STEM dimensions?

2. Literature Review

STEM integration has multiple definitions (Berisha & Vula, 2021; Moore & Smith, 2014; Sanders, 2009). In this study, Sanders' (2009) approach was considered. According to Sanders (2009), STEM integration explores teaching and learning between two or more STEM subject areas. In this context, STEM in primary education literature review is conducted.

STEM education has been given importance since primary school in many developed countries, and numerous studies have been conducted in this field. However, the research is generally carried out with students, pre-service teachers, or teachers in science education area (Siew et al., 2015; Yilmaz et al., 2018). Although studies in primary school teaching have started to increase in recent years, it is possible to say that they are in the minority. Becker and Park (2011) examined the studies on STEM projects and determined that only three of 28 studies were related to STEM education in primary school. In many studies conducted at the primary school level, it has been determined that it has positive effects on students. For example, Miller (2019) stated that learning through coding teaching at the primary school level can lead to students' generalization and higher levels of mathematical thinking. Master et al. (2017) determined that girls who had programming experience increased their higher technology interests and self-efficacy than girls who did not. It has also been determined that STEM applications have positive effects on primary school students' problem-solving skills (Saleh, 2016), and creative thinking (Kwon et al., 2012).

Besides, it was beneficial content knowledge, critical thinking skills, and STEM attitudes (Rehmat, 2015).

Besides, some studies are conducted with pre-service primary teachers and primary teachers in the literature. According to the results, STEM education practices positively affected the thoughts of primary teachers regarding STEM education and engineering-technology (Yıldırım & Türk, 2018), developed their understanding of STEM (Pimthong & Williams, 2021), and it made positive and significant changes in their perceptions of STEM disciplines (Ayaz & Sarıkaya, 2019; Nadelson et al., 2013). As a result of the professional development programs implemented for primary teachers, there was a significant increase in teachers' self-confidence, competence, and STEM perceptions (Nadelson et al., 2013). It developed a positive attitude in the engineering dimension and STEM teaching activity (Nadelson et al., 2009) and there were significant changes in their self-efficacy (Tongchai, 2021). DiFrancesca et al. (2014) conducted a STEM teacher preparation program with pre-service primary teachers to help them gain self-confidence to acquire the primary school curriculum and improve their understanding and skills regarding the engineering dimension. They determined that the attitudes and ideas of teacher candidates improved.

Since the low number of people who successfully implement STEM education at the primary school level will have adverse outcomes; higher education programs should focus on training academically and pedagogically meticulously and diligently to meet qualified primary school STEM teachers (Schmidt & Fulton, 2016). Without a consistent and supportive professional development curriculum for primary teachers, they may struggle to effectively teach STEM topics (National Research Council [NRC], 2007). As such, it is beneficial for pre-service primary teachers to engage in STEM design practices and gain hands-on experience. This study aims to assess the self-efficacy of pre-service elementary school teachers regarding the STEM design process, while also identifying any challenges they may have faced. Furthermore, by determining the level of relation between STEM designs and STEM dimensions, we can identify specific needs and develop appropriate methods, techniques, and strategies to address any issues that arise.

3. Method

The study aimed to determine pre-service teachers' self-efficacy towards STEM, examine the situations they experience during the implementation process, and assess their level of relating their designs with STEM dimensions. The mixed research method was employed in this study. The quantitative data were obtained through the scale while determining their self-efficacy towards STEM. The quantitative part of the research employed a one-group pretest-posttest model aimed at understanding pre-service teachers' self-efficacy regarding STEM. Additionally, qualitative methods, based on open-ended forms, were used to examine pre-service teachers' experiences performing STEM design practices and their levels of relating their designs with STEM dimensions to gain a deeper understanding of the situation.

3.1. Participants

This research was conducted with third-year students enrolled in the Primary Teacher Education department at a state university in Turkey during "Science Teaching" course. As part of the bachelor in Primary Education degree program that prepares teachers for primary teacher grades for K4, it is required to have the necessary equipment in terms of both subject matter knowledge and teaching profession knowledge. The pre-service teachers must take at least 110 credit courses during the four-year period. All participants in the study had received primary teaching lessons since the beginning of their education in the program, covering topics such as initial reading and writing, drama, learning and teaching approaches, teaching principles and methods, and information technology courses, including basic computing skills. Pedagogical courses were introduced mainly in their second year, which included literacy/literature courses, psychology, math and science methods, and student teaching experiences.

During their third year, pre-service teachers took a course the research was conducted, in science teaching, which covered both theoretical and practical aspects of conducting science lessons in primary school. The research involved 52 pre-service teachers, 42 of whom were female and 10 were male. While they had taken classes on basic science and mathematics concepts at the primary school level, they had not previously had any experience with STEM within the scope of their lessons. Participation in the study was voluntary, and consent was obtained from participants while protecting their personal information. The University's Research Ethics Committee approved the study.

3.2. Data Collection Tools

In the study, while trying to reveal the change in the self-efficacy of pre-service primary teachers towards STEM practices, evaluations were made about their experiences throughout the process. Data were gathered both quantitatively (through a scale) and qualitatively (through open-ended forms).

3.2.1. Teacher Self-Efficacy Scale for STEM Practices

The "STEM Practices Teacher Self-Efficacy Scale" developed by Yaman et al. (2018) consists of 18 questions and is a five-point likert type ranging from 1 (never) to 5 (always). One of the study's objectives was to understand how pre-service teachers' experiences influence their self-confidence in STEM. This instrument was selected because it specifically focuses on the self-confidence aspect of the entire scale. The scale is one-dimensional, and the original scale's Cronbach's alpha coefficient value is 0.97, which is valued as 0.92 within this research. The Cronbach alpha value of 0.80 and above indicates that the scale is reliable (Field, 2009). It took approximately 20 minutes to fill the scale during the study. Example items of the scale include such as "I can answer students' questions about STEM"; "I feel competent about implementing STEM practices", and "I can design a good STEM-related activity."

3.2.2. STEM Practices Process Evaluation Form

The researchers developed the 'STEM Practices Process Evaluation Form' to examine what pre-service teachers' have been through in each session and to understand their experiences in detail since the problem determination process. While creating the form, opinions were taken from two different science education experts with Ph.D. degrees in science education and who made publications on STEM education. The final version of the form was given after experts' views. The form consists of three sections: The first section contains information about the problem situation and decision-making processes.

The second section includes information on materials and equipment, and the third section where a detailed explanation of the stage is requested. In addition, pre-service teachers were asked to fill out additional forms to indicate the changes and modifications they made every week. The sample questions of the STEM Practices Process Evaluation Form were shown in the Appendix A. In order to better understand what pre-service teachers experience, they audio-recorded themselves to prevent forgetting the details of the process while making their design of the steps. We also recorded their designs' presentations to see the details of their explanations.

3.2.3. STEM Practices Design Evaluation Form

The researchers developed the 'STEM Practices Design Evaluation Form' for the pre-service teachers to examine the difficulties they had been through. Also, pre-service teachers thought about the improvement elements of the design they made after watching the whole group presentations. While creating the form, opinions were taken from two experts; one of them was a science teacher who had teaching STEM practices for their lessons for seven years. The other expert was a scholar who had a Ph.D. degree on Computer Education and Instructional Technologies. The final version of the form was finalized based on expert feedback. The experts' opinions were related to adding a section that includes making their STEM design in detail if they

had any help and from whom during their STEM design. The form consists of four sections that examine pre-service teachers' opinions about their designs. The form sections include evaluating the strengths and weaknesses of the design, the elements that need to change, and the details that can be improved in the design, respectively. The participants filled the form about in 15 minutes. The sample questions of the STEM Practices Process Evaluation Form were shown in the Appendix B.

3.2.4. *Relating of Designs with STEM Fields- Rubric*

Pre-service teachers were asked to relate their designs with science, technology, mathematics, and engineering disciplines. Studies in the literature were used while preparing the 'Relating Designs with STEM Fields - Rubric' (Akar & Yadigaroglu, 2021), the designs of the pre-service teachers were evaluated according to the rubric. We also took opinions from four experts- two of them were science education scholars with publications on STEM education, and two were educational technologists with a Ph.D. degree in the educational technologies field- during the rubric preparation process. Thus, we prepared a holistic rubric and conducted analyzes according to the level of meeting the criteria in the rubric. Accordingly, success levels were evaluated between '1-3' points, and the groups that did not meet the relevant criteria had a score of '0'. A maximum of 12 points can be obtained from the rubric. The researchers analyzed the rubric separately. In this way, coder reliability was ensured in the data analysis. Compatibility between encoders was calculated as 85 %. The agreement between the coders is expected to be at least 80% (Patton, 2015). The 'Relating of Designs with STEM Fields-Rubric' is shown in Table 1.

3.3. Implementation Process

During the course, it was explained that STEM approach was a pedagogical component of this course, and it would take for 4 weeks to conduct a STEM project meant to help give them first-hand experience and understanding of components of STEM nature. Aside from these 4-weeks of the course, we conducted implementations of various Science Teaching methods in primary education level for the other 10 weeks. The schedule of the course content by week is shown in Table 2.

Through this research, we gave pre-service teachers detailed information about STEM education and its place and importance in science teaching, the area of STEM education in the curriculum, STEM concepts, practical activity examples, and preparation of STEM-based lessons plans. Participants had no prior exposure to the STEM approach in any of their courses. We stated that a STEM design practice would be conducted, and this practice was held in four weeks within this research. Detailed information about the weekly sessions during the implementation process is presented below. After these 10 weeks of the course, the STEM design process started and took four weeks. The parts of the process are explained below in detail.

Part 1: We asked pre-service teachers to work in groups for the STEM design, including three to five people, and they formed 15 groups. Then, we informed what to do during the implementation process. A timetable was presented to them to make their plans and follow the necessary process for the relevant week. Pre-tests were applied. The researchers determined objectives included in the science curriculum and suitable for performing STEM activities. Pre-service teachers were asked to choose their objectives to make authentic applications. Examples of the objectives in the primary science education curriculum are; 'Designing an artificial environment.' and 'Designing for lighting tools that can be used in the future.' was in the form.

Part 2: Pre-service teachers were asked to make a plan to develop activities based on STEM within the framework of the determined objectives. Within the framework of the objectives, they were asked to identify a problem encountered in daily life and to reveal possible solutions. At the same time, pre-service teachers made sketches and approximate cost calculations. During this period, they conducted research for content knowledge necessary for design and essential information (see Appendix C).

Table 1
Relating Designs with STEM Fields- Rubric

Dimensions	Criteria	Sufficient level (3)	Average level (2)	Weak level (1)	Insufficient level /Not mentioned (0)
Science	Relating the chosen subject with the concepts and context related to the science field	The design features were explained clearly and precisely using related science concepts, principles, or statements.	Science concepts, the subject of the problem related to the design, were explained, but relations with the design were not established.	Only the key science concepts, which were the subject of the problem, were mentioned about the design.	
Technology	Explaining the process to be applied for the solution of the chosen problem in terms of selecting suitable materials, components, techniques, tools, equipment	The functions of the materials used in the design and their practical benefits in solving the problem were demonstrated concretely.	Explanations were made on how the developed design could solve the identified problem.	The benefits to be obtained with the design were explained.	
Engineering	Making a design plan for the product, explaining the positive and negative aspects of the design features, and transferring the chosen path for the solution	How the design phase was planned, the working principles were described, and the considerations in selecting materials were explained in detail.	The design and materials' working principle was justified, but the planning process was not explained.	Only the materials used in the developed design were related to the engineering dimension, and detailed information about the design's planning and working process was not presented.	
Mathematics	Explanation using mathematical processing processes (variable selection, formula, graph, etc.) and necessary mathematical concepts in the design development process	The necessary mathematical operations/concepts were used correctly and the reasons for use were related to the design.	Which mathematical operations or mathematical concepts were used in the developed design were stated.	The mathematical dimensions were expressed but no information was given about the concept or operational processes of the design.	

Table 2

The schedule of the course content by weeks

Week	Schedule
1	Features of science, technology, scientific knowledge and scientific methods
2	Historical development of science teaching
3	Science and technology literacy
4	Constructivist approach and science learning and sample activities
5	Features of science curriculum of primary education and relationships between other lessons
6	Features of science curriculum of primary education and relationships between other lessons
7	Science and basic concepts of science education in primary education program
8	Development of science process skills and sample activities (STEM activities)
9	Development of science process skills and sample activities (STEM activities)
10	Concept teaching sample activities on STEM

Part 3: Pre-service teachers were expected to present possible solutions, provide the necessary tools and materials, and try their prototype designs. In this process, we provided information about the materials needed for the designs of the groups and the necessary guidance regarding supplementation tools. During the week, the groups came together and held meetings to work on their designs. In addition, the groups met with researchers during this process and received support about the problems they experienced and exchanged ideas with their peers studying science education (see Appendix D).

Part 4: In the last session of the process, pre-service teachers completed their designs and shared them with their other friends. The post-tests were applied as well. The participants were asked to fill out the design evaluation forms. Moreover, during the development of activities based on STEM, their opinions were taken in each session. They had experience with the STEM cycle by addressing a problem situation in this context. As a result of the pre-service teachers' work with their groups, 15 designs emerged. Examples of these designs are the rainwater utilization model, environmentally-friendly parking lot model, plant irrigation model, solar oven model, domestic animal shelter model with waste materials.

3.4. Data Analysis

We statistically analyzed the 'STEM Practices Teacher Self-Efficacy Scale' data in the study. The normality distribution of student scores was checked with the Kolmogorov-Smirnov test, and we determined that it provided the normality assumptions. Then, Paired sample t-test was used to assess the effect of STEM practices on pre-service teachers' self-efficacy. In addition, the effect value was examined to understand the size of the difference between the pre-test and post-test. Besides, the qualitative data obtained during the design processes were analyzed using content analysis. During the content analysis, we made open coding and created relevant themes.

The data were coded with open coding (Strauss & Corbin, 1990), then a common code category (theme) and sub-categories were determined for the codes regarding the same title or subject. The codes were finalized, and the codes were combined and presented under the themes. The reliability of the data was tried to be ensured by the triangulation method (Merriam, 2009). Thus, encoder reliability was ensured by the separate coding of two researchers who are science education field experts (Patton, 2015). It was found to be 85 % consistent. The data obtained from the open-ended forms were transferred to the Nvivo program. While giving examples of the analyzed data obtained from the groups formed by the pre-service teachers, the group names started with the letter 'G' and continued with the number.

4. Results

The research aimed to determine how the practices affect the STEM self-efficacy perceptions of pre-service primary teachers. The 'STEM Practices Teacher Self-Efficacy Scale' was applied to the

participants at the beginning and end of the process. Single-group paired samples *t*-test was used. The results of the analysis are given in Table 3.

Table 3

STEM Practices Teacher Self-Efficacy Scale t-test findings and effect sizes

<i>Tests</i>	<i>N</i>	<i>Mean</i>	<i>SD</i>	<i>df</i>	<i>t</i>	<i>p</i>	<i>Standardized coefficient (β)</i>
Pre-test	52	60.54	8.73	51	10.82	<.01	0.534
Post-test	52	73.30	7.98				

Pre-test and post-test scores on the STEM Practices Teacher Self-Efficacy were shown in Table 3. The STEM implementation had a positive and statistically significant but moderate effect on the pre-service teachers' perceived self-efficacy levels ($\beta = 0.534$, $p < .05$). So, it is possible to indicate that the STEM practices carried out positively affect the self-efficacy perceptions of pre-service teachers.

Another question was to search for what they experienced during the design process. In this context, "How did the pre-service primary teachers decide on the process of designing STEM practices?" was asked. The data obtained from the STEM Practices Process Evaluation Forms of the primary pre-service teachers were analyzed. In designing the studies they would do, the pre-service teachers made detailed explanations about the planning process after deciding on the problem and after determining the problem. In this context, by creating codes according to the answers obtained, themes such as problem selection and planning process and sub-themes that explain this process in detail were formed. The themes, sub-themes, and codes are shown in Table 4.

Table 4

Themes and codes regarding the process of designing STEM practices

<i>Themes and sub-themes</i>	<i>Codes</i>
Problem selection	
Problems from daily life	Noise Deficiencies in the habitats of animals and their nutritional needs Lack of lighting in children's playgrounds Waste of energy resources Shortage of parking space Waste of bread
Observations	Problems of watering plants Failure to use rainwater Waste of water
Considering students' lives	Choosing problems according to students' experience
Choosing current problems	Renewable energy use
Planning process	
Research	Reading articles on STEM Reviewing STEM project examples
Communication	Seeking advice from experts in science education Interviewing peers studying science education
Design	Making designs for primary students' level Creating scenarios suitable for the problem situation Trying to create a useful product

In Table 4, it is seen that at the beginning of the design process, the pre-service teachers chose the problem situations and talked about the factors that caused them to select the problem. Accordingly, the main factors in choosing the relevant problem are the situations they experience

in daily life and disturb them, the observations they make, the fact that the problem is related to the students' life and current problems. In this context, it was seen that they talked about many issues. For example, when determining the G3 explained their problem, as:

We observed that while walking on the road in rainy weather, the rainwater flowing from the roofs of the houses flowed directly to the ground. The question of how we can transform this situation, namely, how we can change the wasted rainwater into an efficient one, came to our minds.

Thus, their observations led them to find the problem situation as to how to use rainwater efficiently. In addition, pre-service teachers gave information about the planning processes and explained how they followed the process. They worked with the group carried out studies on design not only in the course where the application was made but also in other times. One of the groups that carried out the study while creating the design, G2 indicated that:

We created the idea stage of this activity in the house we live. We discussed how to develop a project about the problem we found and what materials we should use. After we identified the problem and determined the scenario in which we would move forward, we wrote our plan. At the end of the plan, we created the draft drawing of the design that we will realize.

In G8, the decision-making process on the problem situation was explained by stating:

First of all, we did more detailed research on STEM. We read articles online and talked to a friend of ours in the science teaching department. We searched for and examined how STEM activity is designed. We discussed ideas with our friends and decided on the problem situation of our STEM activity.

In the planning process, besides the in-group discussions, other sources that may be relevant were also contacted, research was made from the sources, and ideas were discussed. Another situation examined regarding the experiences in the design process was "What kind of challenges did the pre-service primary teachers experience during the STEM implementation process?" was in the form. In this context, the research examined the difficulties pre-service teachers experienced during the STEM practice process. The findings of difficulties experienced during the STEM implementation process are shown in Table 5.

Table 5

Difficulties experienced during the STEM implementation process

<i>Themes and sub-themes</i>	<i>Codes</i>
Difficulties experienced	
Problem-based challenges	Difficulties in limiting the problem Difficulties in finding current problems Difficulties in finding original problems
Difficulties based on lack of knowledge and experience	Difficulties in the design process Difficulties in connecting solar panel Difficulties in making electrical circuits Selecting appropriate tools and materials Difficulties in sketching
Tool-based challenges	Making the product more durable Visual design and aesthetic dimension
Cost-driven challenges	The high cost of solving the problem To do the project with simple tools due to economic limits

According to Table 5, the pre-service teachers listed the difficulties related to the STEM implementation process as problems associated with the problem-based, complications due to lack of knowledge and experience, material-based and cost-oriented difficulties. As an example of the problems experienced by G6, among the difficulties encountered in the process:

We identified many different problem areas, but we tried to choose the one that is both the least costly and the easiest to use and supply materials. At this point, we had differences of opinion and finally came to a decision.

It is seen that the group had difficulties in terms of cost, which affects the problem selection, but in the end, they come to a joint decision through group discussions. G9, on the other hand, talked about the lack of knowledge and experience in design related to the difficulties experienced in the process. They mentioned that:

We couldn't get the sticks we used to create our prototype to rotate. We realized that we had to drill a hole in the bottom of the bottle; we made a hole, shortened the rope's length, and tried again. We had a little difficulty because we didn't know about them.

It is understood that G9 had difficulties creating the mechanism of the design because they had never carried out a similar application before, and they had deficiencies in their knowledge about the factors affecting the operation of the mechanism. Within the scope of the fourth research question of the study, the forms were analyzed using the 'Relating of Designs with STEM Fields- Rubric' to examine the level of relating the designs made by the pre-service primary teachers with the STEM dimensions. In this context, we searched for "How is the level of relating the designs made by the pre-service primary teachers with the STEM dimensions?" Each group formed by the pre-service teachers was scored, and the distribution of the scores they got from the rubric according to STEM fields is shown in Table 6.

Table 6

Scores of the groups from Relating of Designs with STEM Fields- Rubric

<i>Dimensions</i>	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	<i>Scores of the sections</i>
Science	3	3	1	1	1	1	2	1	1	1	0	3	2	1	2	23
Technology	2	1	1	1	1	2	1	1	1	1	1	1	3	1	2	20
Engineering	1	2	1	1	1	0	2	0	0	1	1	2	3	1	1	18
Mathematics	3	2	1	1	1	2	2	1	1	2	2	3	2	2	1	26
Total	9	8	4	4	4	5	7	3	3	5	4	9	10	5	6	

According to Table 6, it is seen that the field in which the groups got the highest score from the rubric was mathematics, followed by science, technology, and engineering, respectively. Thus, only three out of 15 groups scored above 9 out of 12 points and showed a success rate of at least 75%. Many groups had a total score of 3 and 4, and it was seen that the success rate of associating their designs with STEM fields was between 30% and 40%. Moreover, only one group received 3 points by adequately relating their designs with technology and engineering dimensions.

5. Discussion

There has been an increase in research and reports regarding the STEM field at the primary education level and the benefits of using the STEM approach, but there is still a need for research in this area (Madden et al., 2016). According to the research findings, experiencing STEM teaching positively affected the self-efficacy perceptions of pre-service primary teachers. This finding is consistent with many studies in the literature (Fenton & Essler-Petty, 2019; Jaipal-Jamani, & Angeli, 2017; Johnson et al., 2021; Nadelson et al., 2009). It is possible to say that this practice had a positive effect on them since the pre-service primary teachers participating in this study had no experience with STEM and had not taken a course in this content before.

Another finding of the study was that pre-service primary teachers' choices to make their STEM design were mostly based on their problems primarily based on their experiences of daily life observations and also considered that the problem situation should be suitable for the primary level and include everyday life materials during the design process. While planning for the design,

they researched STEM, examined STEM project examples (Aslan-Tutak et al., 2017), and had advice from experts in science education.

Another research finding showed pre-service primary teachers' STEM experience had some difficulties during their STEM design process. From the problem-solving process to the design completion, they had some challenges mostly due to their lack of knowledge and experience and also tool-based, and cost-driven. This can be explained by the fact that pre-service teachers lack STEM experience (Plumley, 2019; Prinsley & Johnston, 2015) and limited knowledge about STEM design stages. Primary school teachers have pedagogical and content problems in STEM design and need professional development (Lesseig et al., 2016). Professional development experiences help increase teachers' knowledge and skills and change their attitudes using their new knowledge and skills, attitudes, and beliefs to improve the content of their instruction, their approach to pedagogy, or both (Desimone, 2009).

The last finding reached from the study was related to the inadequacy of pre-service teachers' level of relating their designs with STEM dimensions. They showed poor performance in explaining the STEM dimensions in their designs and relating them with concepts. This result is particularly evident when explaining and relating the technology and engineering dimensions. Yıldırım and Türk (2018) determined that pre-service primary had misconceptions about technology and engineering and a lack of knowledge about science, mathematics, and engineering dimensions. It was determined that primary school teachers thought that engineering, technology, and design dimensions were critical, but they were unfamiliar with these concepts (Hsu et al. 2011). Similarly, most of the primary teachers feel less prepared to teach science (Plumley, 2019) and feel incompetent in teaching STEM (Prinsley & Johnston, 2015). This research also revealed that they are insufficient in distinguishing technology and engineering dimensions and associating them with design, to the point of relating their designs with STEM dimensions. It is thought that they get partially higher scores in science and mathematics dimensions because they have taken previous courses on these contents and have more experience throughout their entire educational lives. Geng et al. (2019) determined that only 5% of the participants, including nearly half of those who were primary teachers, considered themselves sufficient for STEM education. Many studies reveal that STEM design-oriented practices and professional development programs improve primary teachers' self-efficacy and perceptions of teaching STEM (Difrancesca, 2014; Nadelson, 2013; Nadelson et al., 2009; Tongchai, 2021). Thus, it is essential to provide professional development and pedagogical support during their careers.

6. Conclusion

This study attempted to reveal pre-service primary teachers experiences of STEM practice and determine their self-efficacy in STEM teaching. Consequently, enhancing pre-service primary teachers' ability to teach STEM concepts and facilitate STEM activities can significantly impact students' potential to establish a strong foundation for STEM success and pursue STEM-related careers. Since STEM applications are integrated into science lessons taught by primary teachers, it is crucial for pre-service teachers to possess high self-efficacy and experience to excel in STEM teaching. Therefore, it is imperative to conduct studies that ensure teachers' competencies, self-efficacy, experiences, and attitudes are positive. Apart from other studies, the research focused on a better understanding of STEM design practice and evaluating the level of relating their designs to the STEM dimensions of pre-service primary teachers and their experiences during the STEM design process. It is revealed that They associated their designs well with science and mathematics dimensions but not with technology and engineering. We had detailed information that the pre-service teachers had difficulties identifying the problem, choosing tools, and calculating costs. They also mentioned their lack of knowledge and experience while making a STEM design. We recommend that pre-service primary teachers take elective courses that enable them to utilize the design and engineering design cycle and foster interdisciplinary relationships. Moreover, it is essential to examine the teaching competencies of STEM subjects in the curriculum, with particular

emphasis on supporting technology and engineering dimensions and guiding them with sample practices. Further research on the integration of STEM dimensions by pre-service teachers can provide valuable insights into the types of support and professional development they need to effectively integrate these dimensions into their teaching practices.

7. Limitations

This study focused on a four-week science teaching course, where participants engaged in three-hour practices per week. In order to gain a more comprehensive understanding, it may be beneficial to conduct a similar study on a larger group of students over an extended period in future research.

Author contributions: All authors contributed to all the processes of the manuscript, including conceptualization, data collection, analysis of the data, and reporting.

Data availability: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declaration of interest: The authors disclose that they have no actual or perceived conflicts of interest.

Ethical statement: This study was approved by the Ethics Committee of the Sakarya University Rectorate, with Decision No. 18, taken during the meeting held on May 12, 2022 (Meeting No. 07).

Funding information: No funding was received for this manuscript.

References

- Akar, H. & Yadigaroglu, M. (2021). The effect of the science, technology, engineering and mathematics (STEM) based activities on the 5th grade students' association of the concepts in the substance and change unit with the daily life abstract. *Journal of Erzurum University Faculty of Education*, 23(1), 57-81. <https://doi.org/10.17556/erziefd.656886>
- Aslan-Tutak, F., Akaygun, S., & Tezsezen, S. (2017). Collaboratively learning to teach STEM: Change in participating pre-service teachers' awareness of STEM. *Hacettepe University Journal of Education*, 32(4), 794-816. <https://doi.org/10.16986/HUJE.2017027115>
- Ayaz, E., & Sarıkaya, R. (2019). The effect of engineering design-based science teaching on the perceptions of classroom teacher candidates towards STEM disciplines. *International Journal of Progressive Education*, 15(3), 13-27. <https://doi.org/10.29329/ijpe.2019.193.2>
- Bakırcı, H., & Karışan, D. (2018). Investigating the pre-service primary school, mathematics and science teachers' STEM awareness. *Journal of Education and Training Studies*, 6(1), 32-42. <https://doi.org/10.11114/jets.v6i1.2807>
- Bandura, A. (1997). *Self-efficacy: The exercise of control*. W.H. Freeman and Company.
- Becker, K., & Park, K. (2011). Integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students learning: A meta-analysis. *Journal of STEM Education*, 12(5), 23-37.
- Berisha, F., & Vula, E. (2021). Developing preservice teachers STEM understanding and pedagogical practices. *Frontiers in Education*, 6, 1-10. <https://doi.org/10.3389/educ.2021.585075>
- Blackley, S., & Howell, J. (2015). A STEM narrative: 15 years in the making. *Australian Journal of Teacher Education*, 40(7), 102-112.
- Blackmore, K., Howard, C., & Kington, A. (2018). Trainee teachers' experience of primary science teaching, and the perceived impact on their developing professional identity. *European Journal of Teacher Education*, 41(4), 529-548. <https://doi.org/10.1080/02619768.2018.1462330>
- Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher*, 70(1), 30-35.
- Charette, R. N. (2015). STEM sense and nonsense. *Educational Leadership*, 72(4), 79-83.

- Depaepe, F., & König, J. (2018). General pedagogical knowledge, self-efficacy and instructional practice: Disentangling their relationship in pre-service teacher education. *Teaching and Teacher Education*, 69, 177-190. <https://doi.org/10.1016/j.tate.2017.10.003>
- Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher*, 38(3), 181-199. <https://doi.org/10.3102/0013189X08331140>
- DiFrancesca, D., Lee, C., & McIntyre, E. (2014). Where is the "E" in STEM for young children? Engineering design education in an elementary teacher preparation program. *Issues in Teacher Education*, 23(1), 49-64.
- Fenton, D., & Essler-Petty, S. (2019). Self-efficacy and STEM: An integrated pedagogical approach for pre-service elementary teachers. *International Journal for Cross-Disciplinary Subjects in Education*, 10(4), 4160-4168.
- Field, A. (2009). *Discovering statistics using Spss*. Sage.
- Geng, J., Jong, M. S. Y., & Chai, C. S. (2019). Hong Kong teachers' self-efficacy and concerns about STEM education. *The Asia-Pacific Education Researcher*, 28(1), 35-45. <https://doi.org/10.1007/s40299-018-0414-1>
- Greca Dufranc, I. M., García Terceño, E., Fridberg, M., Cronquist, B., & Redfors, A. (2020). Robotics and early-years STEM education: The botSTEM framework and activities. *European Journal of STEM Education*, 1, 1-13. <https://doi.org/10.20897/ejsteme/7948>
- Gurler, S. (2022). State of prediction of the critical thinking dispositions of primary school teacher candidates through their self-efficacy for STEM practices. *Participatory Educational Research*, 9(3), 61-81. <https://doi.org/10.17275/per.22.54.9.3>
- Hourigan, M., O'Dwyer, A., Leavy, A. M., & Corry, E. (2022). Integrated STEM—a step too far in primary education contexts? *Irish Educational Studies*, 41(4), 687-711. <https://doi.org/10.1080/03323315.2021.1899027>
- Hsu, M. C., Purzer, S., & Cardella, M. E. (2011). Elementary teachers' views about teaching design, engineering, and technology. *Journal of Pre-College Engineering Education Research*, 1(2), 31-39. <https://doi.org/10.5703/1288284314639>
- Jaipal-Jamani, K., & Angeli, C. (2017). Effect of robotics on elementary pre-service teachers' self-efficacy, science learning, and computational thinking. *Journal of Science Education and Technology*, 26(2), 175-192. <https://doi.org/10.1007/s10956-016-9663-z>
- Johnson, T. M., Byrd, K. O., & Allison, E. R. (2021). The impact of integrated STEM modeling on elementary pre-service teachers' self-efficacy for integrated STEM instruction: A co-teaching approach. *School Science and Mathematics*, 121(1), 25-35. <https://doi.org/10.1111/ssm.12443>
- Kurup, P. M., Li, X., Powell, G., & Brown, M. (2019). Building future primary teachers' capacity in STEM: based on a platform of beliefs, understandings and intentions. *International Journal of STEM Education*, 6(1), 1-14. <https://doi.org/10.1186/s40594-019-0164-5>
- Kwon, S. B., Nam, D. S., & Lee, T. W. (2012). The effects of STEAM-based integrated subject study on elementary school students' creative personality. *Journal of the Korea Society of Computer and Information*, 17(2), 79-86. <https://doi.org/10.9708/jksci.2012.17.2.079>
- Le, T. X., & Bui, V. H. (2021). STEM teaching skills of primary school teachers: The current situation in Ho Chi Minh City, Vietnam. *Journal of Education and e-Learning Research*, 8(2), 149-157.
- Lee, M. H., Chai, C. S., & Hong, H. Y. (2019). STEM education in Asia Pacific: Challenges and development. *The Asia-Pacific Education Researcher*, 28(1), 1-4. <https://doi.org/10.1007/s40299-018-0424-z>
- Lesseig, K., Slavitt, D., Nelson, T. H., & Seidel, R. A. (2016). Supporting middle school teachers' implementation of STEM design challenges. *School Science and Mathematics*, 116(4), 177-188. <https://doi.org/10.1111/ssm.12172>
- Madden, L., Beyers, J., & O'Brien, S. (2016). The importance of STEM education in the elementary grades: Learning from pre-service and novice teachers' perspectives. *The Electronic Journal for Research in Science & Mathematics Education*, 20(5), 1-18.
- Master, A., Cheryan, S., Moscatelli, A., & Meltzoff, A. N. (2017). Programming experience promotes higher STEM motivation among first-grade girls. *Journal of Experimental Child Psychology*, 160, 92-106. <https://doi.org/10.1016/j.jecp.2017.03.013>
- Meng, C., Idris, N., Leong, K. E., & Daud, M. (2013). Secondary school assessment practices in science, technology and mathematics (STEM) related subjects. *Journal of Mathematics Education*, 6(2), 58-69.
- Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation*. Jossey-Bass.

- Miller, J. (2019). STEM education in the primary years to support mathematical thinking: Using coding to identify mathematical structures and patterns. *ZDM Mathematics Education*, 51(6), 915-927. <https://doi.org/10.1007/s11858-019-01096-y>
- Moore, T. J., & Smith, K. A. (2014). Advancing the state of the art of STEM integration. *Journal of STEM Education: Innovations and Research*, 15(1), 5-10.
- Murphy, C., & Beggs, J. (2003). Children's perceptions of school science. *School Science Review*, 84, 109-116.
- Nadelson, L. S., Callahan, J., Pyke, P., Hay, A., Dance, M., & Pfister, J. (2013). Teacher STEM perception and preparation: Inquiry-based STEM professional development for elementary teachers. *The Journal of Educational Research*, 106(2), 157-168. <https://doi.org/10.1080/00220671.2012.667014>.
- Nadelson, L. S., Callahan, J., Pyke, P., Hay, A., & Schrader, C. (2009). *A systemic solution: Elementary teacher preparation in STEM expertise and engineering awareness* [Paper presentation]. ASEE Annual Conference and Exposition, Conference Proceedings, June 14-17, Austin, TX.
- National Research Council [NRC]. (2007). *Taking science to school: Learning and teaching science in grades K-8*. National Academy Press.
- National Research Council [NRC]. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. National Academy Press.
- Pajares, F., & Schunk, D. (2001). The development of academic self-efficacy. *Development of achievement motivation. United States*, 7, 1-27.
- Partnership for 21st Century Skills (P21) (2019). *Framework for 21st century learning*. Author.
- Patton, M. Q. (2015). *Qualitative evaluation and research methods*. Sage.
- Pimthong, P., & Williams, P. J. (2021). Methods course for primary level STEM pre-service teachers: Constructing integrated STEM teaching. *EURASIA Journal of Mathematics, Science and Technology Education*, 17(8), 2-14.
- Pimthong, P., & Williams, J. (2018). Pre-service teachers' understanding of STEM education. *Kasetsart Journal of Social Sciences*, 41(2), 289-295. <https://doi.org/10.1016/j.kjss.2018.07.017>
- Plumley, C. L. (2019). *2018 NSSME+: Status of elementary school science*. Horizon Research.
- Prinsley, R., & Johnston, E. (2015). *Transforming STEM teaching in Australian primary schools: Everybody's business*. Australian Government-Office of the Chief Scientist.
- Rehmat, A. P. (2015). *Engineering the path to higher-order thinking in elementary education: A problem-based learning approach for STEM integration* [Unpublished doctoral dissertation]. Nevada University, Las Vegas.
- Rittmayer, A. D., & Beier, M. E. (2009). Overview: Self-efficacy in STEM. *SWE-AWE CASEE Overviews*, 1(3), 1-12.
- Salar, R. (2021). Awareness and self-efficacy of pre-service science teachers about STEM education: A qualitative study. *Asia-Pacific Forum on Science Learning and Teaching*, 20(1), 1-21.
- Saleh, A. H. (2016). A proposed unit in the light of STEM approach and its effect on developing attitudes toward (STEM) and problem solving skills for primary students. *International Interdisciplinary Journal of Education*, 5(7), 186-217.
- Sanders, M. (2009). STEM, STEM education, STEMmania. *The Technology Teacher*, 68(4), 20 -26.
- Schmidt, M. & Fulton, L. (2016). Transforming a traditional inquiry-based science unit into a STEM unit for elementary pre-service teachers: A view from the trenches. *Journal of Science Education and Technology*, 25(2), 302-315. <https://doi.org/10.1007/s10956-015-9594-0>
- Siew, N. M., Amir, N., & Chong, C. L. (2015). The perceptions of pre-service and in-service teachers regarding a project-based STEM approach to teaching science. *SpringerPlus*, 4, 8. <https://doi.org/10.1186/2193-1801-4-8>
- Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research*, 2(1), 28-34. <https://doi.org/10.5703/1288284314653>
- Strauss, A., & Corbin, J. (1990). *Basics of qualitative research*. Sage.
- Sutaphan, S., & Yuenyong, C. (2019). STEM education teaching approach: Inquiry from the context based. *Journal of Physics: Conference Series*, 1340(1), 012003.
- Tongchai, A. (2021). The effects of a professional development on teachers' self-efficacy in promoting thinking and problem-solving skills. *Journal of Physics: Conference Series*, 1957, 012032.
- Xie, Y., Fang, M., & Shauman, K. (2015). STEM education. *Annual Review of Sociology*, 41, 331-357. <https://doi.org/10.1146/annurev-soc-071312-145659>

- Yaman, C., Ozdemir, A & Vural, R. A. (2018). Development of the teacher self-efficacy scale for STEM practices: A validity and reliability study. *Adnan Menderes University Journal of Social Sciences Institute*, 5(2), 93-104. <https://doi.org/10.30803/adusobed.427718>
- Yıldırım, B., & Türk, C. (2018). Pre-service primary school teachers' views about STEM education: An applied study. *Trakya Journal of Education*, 8(2), 195-213.
- Yılmaz, A., Gülgün, C., Çetinkaya, M., & Doganay, K. (2018). Initiatives and new trends towards STEM education in Turkey. *Journal of Education and Training Studies*, 6, 1-10.
- Zakariya, Y. F. (2020). Effects of school climate and teacher self-efficacy on job satisfaction of mostly STEM teachers: a structural multigroup invariance approach. *International Journal of STEM Education*, 7(1), 1-12. <https://doi.org/10.1186/s40594-020-00209-4>
- Zhou, S. N., Zeng, H., Xu, S. R., Chen, L. C., & Xiao, H. (2019). Exploring changes in primary students' attitudes towards science, technology, engineering and mathematics (STEM) across genders and grade levels. *Journal of Baltic Science Education*, 18(3), 466.

Appendices

Appendix A. STEM Practices Process Evaluation Form

Considering your experiences in STEM practices, please indicate your views of the strengths and weaknesses of your design and the elements that can be improved below.

Strengths of the design	Weaknesses of the design	How to be improved the design

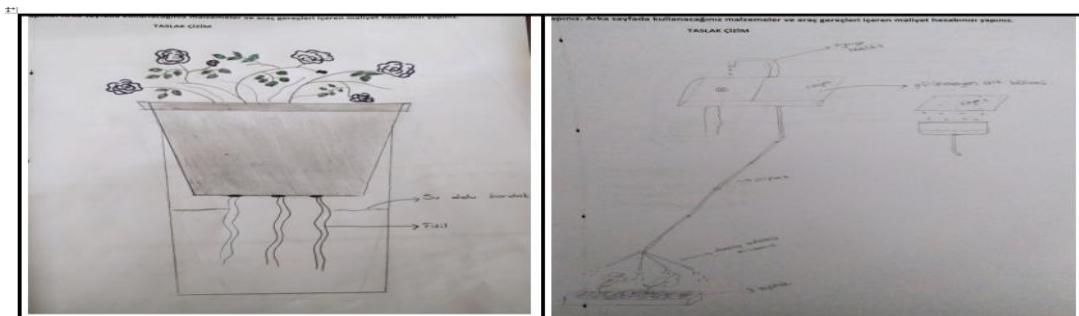
Appendix B. Stem Practices Process Evaluation

Please complete all parts of the form, which seeks your views during your STEM design process in each step.

Part 1
Problem situation and decision-making processes
What is the topic of your problem?
How did you decide your problem?
What did you experience while deciding your problem?

Appendix B continued

Part 2 Deciding on materials and equipment
Which materials did you use while creating your design?
How did you decide to use your materials to make your design?
Part 3 Designing process
How did you plan to make your design? Please explain in detail.
Please explain which stage you are at in the design plan.
Did you get any help during your STEM design? If yes, please explain who supported you.
If you would like to add something else, please mention it here.

Appendix C. Sketches of the pre-service teachers' of the plant irrigation model and rainwater utilization model


Appendix D. Examples of designs of domestic animal shelter model with waste materials and environmentally-friendly parking lot model

